Fermi National Accelerator Laboratory
Particle Physics Division

Mechanical Department Engineering Note

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Title: ***DES 2k x 4k V1 CCD Module Flatness,***
Thickness, & Edge Alignment Results

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Reviewer(s): ---

Key Words: *DES / CCD*

Abstract/Summary:

A sample of V1 CCD modules have been inspected for flatness, thickness, and profile alignment. Results found that all modules passed the flatness specifications except two, which failed in the regions where small double-sticky tape pieces are used during assembly. These tape pieces will be eliminated from the assembly process for the V2.1 redesign.

Average module thickness was found to be 4.4 microns less than nominal, with a range in average thickness of 4 microns between modules.

The maximum edge location deviation from nominal was found to be 38 microns. Any systematic misalignments are smaller than the diametral slop in the mounting pin fits (25 microns). The measurement technique of picking local maximums was repeatable despite the Si diced edge quality under magnification.

Applicable Codes: *N/A*

INTRODUCTION

Several V1 2k x 4k modules have been constructed as part of the WBS 1.2.2.2.1 CCD packaging effort. The module design is shown in Ref. 1 and is discussed in Refs 2 through 4. This report discusses measurements taken to evaluate several aspects of module construction:

- CCD Flatness, which is needed to maintain good image focus in order to meet DES science goals,
- Module Thickness, which is related to flatness since multiple modules will be arranged in an array and variations in height must be minimized to maintain image focus, and
- CCD Edge Alignment, which must be controlled in order to facilitate packing modules in an array with 0.5 mm nominal gaps between CCD edges.

FLATNESS MEASUREMENTS

These inspections are performed to verify compliance with the following module specifications:

T28 – RMS variations within 1 cm^2 are < 3 microns
T29 – Adjacent 1 cm^2 regions are within 10 microns of each other.

We have measured the flatness of the electrically non-functional sample of CCDs using a confocal chromatic distance measurement instrument (DMI) as discussed in Reference 3. This measurement is especially important because it is made at the operating temperature of 173 K. To our knowledge, this direct measurement of CCD flatness at operating temperature is unique in camera construction.

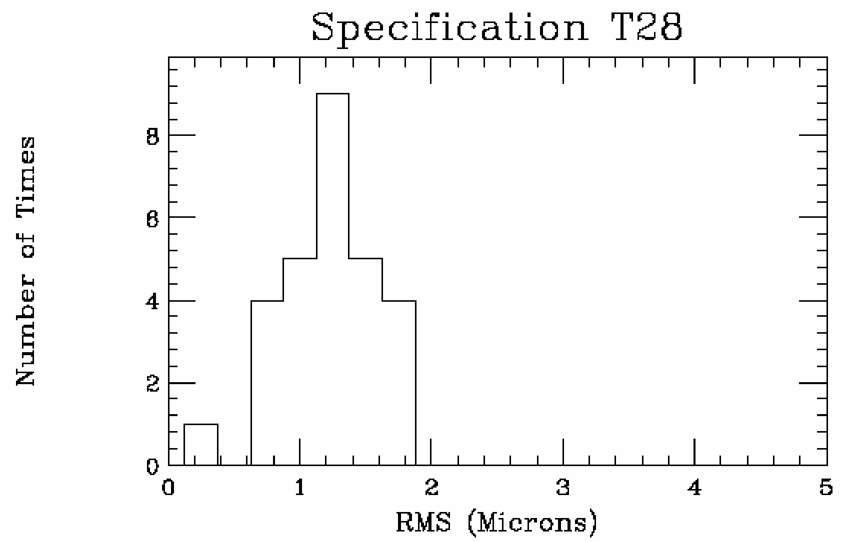
The CCD is mounted in an evacuated dewar and cooled with liquid nitrogen. A heater controlled by a Lakeshore Temperature Controller maintains the temperature of the CCD. The CCD backside surface is visible in the dewar through a fused silica window. The DMI is scanned across the surface of the CCD and the distance is recorded in a file for analysis. While details of the procedure vary from device to device, the basic analysis process is as follows:

1. Measure the distance to surface points on a 0.5 x 0.5 mm grid over the 31 mm x 61 mm CCD surface. Typically, each distance measurement is the average value of 20 consecutive measurements made at the same point. The RMS of the 20 measurements is 2 to 4 microns. This full grid is measured 2 to 5 times.
2. The plane which best fits the data is calculated for and subtracted from each individual grid of data points.
3. The grids are combined. When there are pairs of grids they are combined by averaging the data points taken at the same position. This reduced the measurement by square-root of 2. When there are 3 or 5 measurement grids, they are combined by taking the median of the measurements with an uncertainty approximately square-root of the number of measurements.
4. Calculation of information for specification T28 is made from the combined data. The CCD is divided into 1 cm x 1 cm (parent) subsurfaces and also into 1/4 cm x 1/4 cm (daughter) subsubsurfaces. Along the edges there are smaller subsurfaces because the measurement isn't an integral number of cms in that dimension. The RMS difference of all measurements within each daughter subsubsurface (typically from 25 grid points) from the parent subsurface is calculated. This provides information for spec T28.
5. Calculation of the information for specification T29 is made. The mean elevation of each parent subsurface is compared from the directly adjacent neighbors. This information is used for spec T29.
6. A report summarizing the measurements and results is automatically generated.

Module #	Measurement Temperature (K)	Method and # grids	Spec T28	Spec T29	Comment
S0-03	152	Mean of 2	Fail	Pass	Fails T28 in one point
S0-03	294	Mean of 2	-	-	
S1-01	173	Mean of 2	Pass	Pass	
S1-02	173	Mean of 2	Fail	Pass	Fails T28 in 1 to 4 points. Repeated 4x.
S1-02	294	Median of 5	-	-	Repeated 7x to study glass systematics.
S1-03	173	Mean of 2	Pass	Pass	
S1-05	173	Mean of 2	Pass	Pass	Repeated 3x with same results.
S1-09	173	Mean of 2	Pass	Pass	Repeated 2x with same results.
S1-17	173	Mean of 2	Fail	Pass	Fails T28 in one point
S1-17	173	Median of 3	Fail	Pass	Fails T28 in the same point

Results of the measurements of seven CCDs are shown in the Table above. Five of seven passed spec T28. Two had subsurface variations in height with RMS greater than 3 microns in 1 to 4 places along the edges. These are thought to be related to “bumps” in the location of small pieces of tape used to hold the CCD to the AlN card in a gluing step of the packaging process. All seven passed spec T29, the global flatness spec. Figure 1 shows a histogram of the RMS difference of ¼ cm x ¼ cm subsubsurfaces from the 1 cm x 1 cm surface on which they reside. It also shows a second histogram, the vertical differences between adjacent one cm^2 subsurfaces. Figure 2 shows the surface of S1-05 with measurements averaged into 2.5 mm x 2.5 mm subsurfaces and is in the form of a color contour plot.

Some systematic effects in the distance measurement are known to exist. We are working on corrections to the data. These include what appears to be a 2 micron low spot in the stage which moves the DMI horizontally, and a few-micron correction due to either a non-uniform index of refraction or a physical warping of the fused-silica window. Those effects are small enough that they will not change whether the CCD passes or fails T28 or T29. A third systematic may be, in part, responsible for the two failures in T28. When there is an abrupt change in the reflection angle of the sample, such as might occur in the location of an abrupt, few-micron tall, Λ-shaped “bump”, it is possible that the DMI may report a measurement with a large systematic error. All these affects are under investigation.



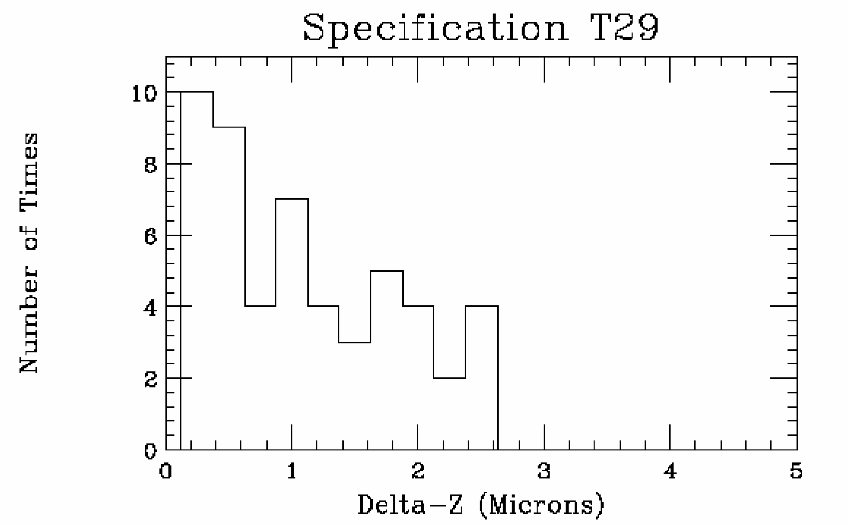


Figure 1. Upper: The RMS of difference of ¼ cm x ¼ cm subsubsurfaces from 1 cm^2 subsurfaces as calculated for specification T28 for S1-05. Specification T28 is that this quantity should be less than 3 microns. The device passes T28. Lower: The height difference between adjacent 1 cm^2 subsurfaces on S1-05 as calculated for specification T29. The specification is that this quantity should be within 10 microns. The device easily passes T29.

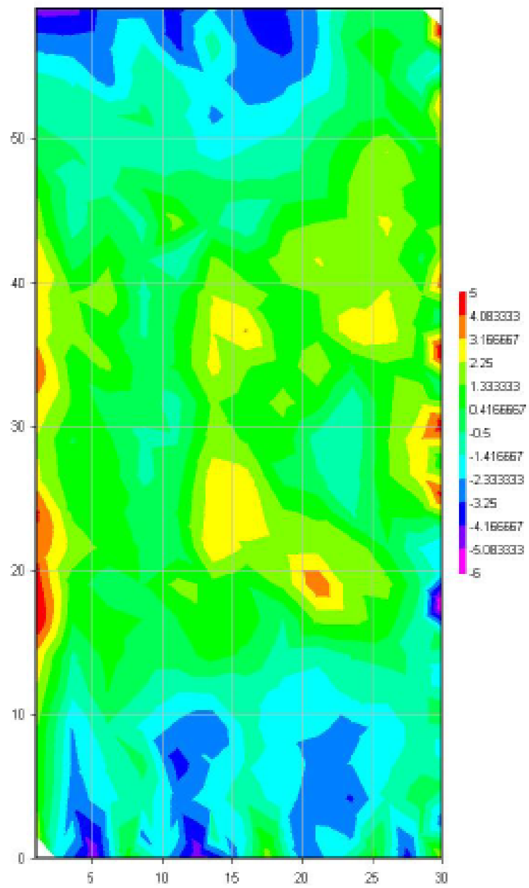


Figure 2. Flatness results for S1-05. The x and y-axes units are mm. The color corresponds to the difference from the best-fit-plane in units of microns. Blue color indicates taller (closer to the DMI). Red indicates shorter (further from the DMI). This CCD passes both flatness specifications.

In addition, as is indicated in the Table, for some CCDs the flatness measurements was made both at room temperature and operating temperature. This provides data for determining the change in shape of the CCD as it is cooled. Results for S1-05 are shown in Fig. 3. The plot shows the shape of the surface at 173k minus the shape at 294k. We call these “warp plots”.

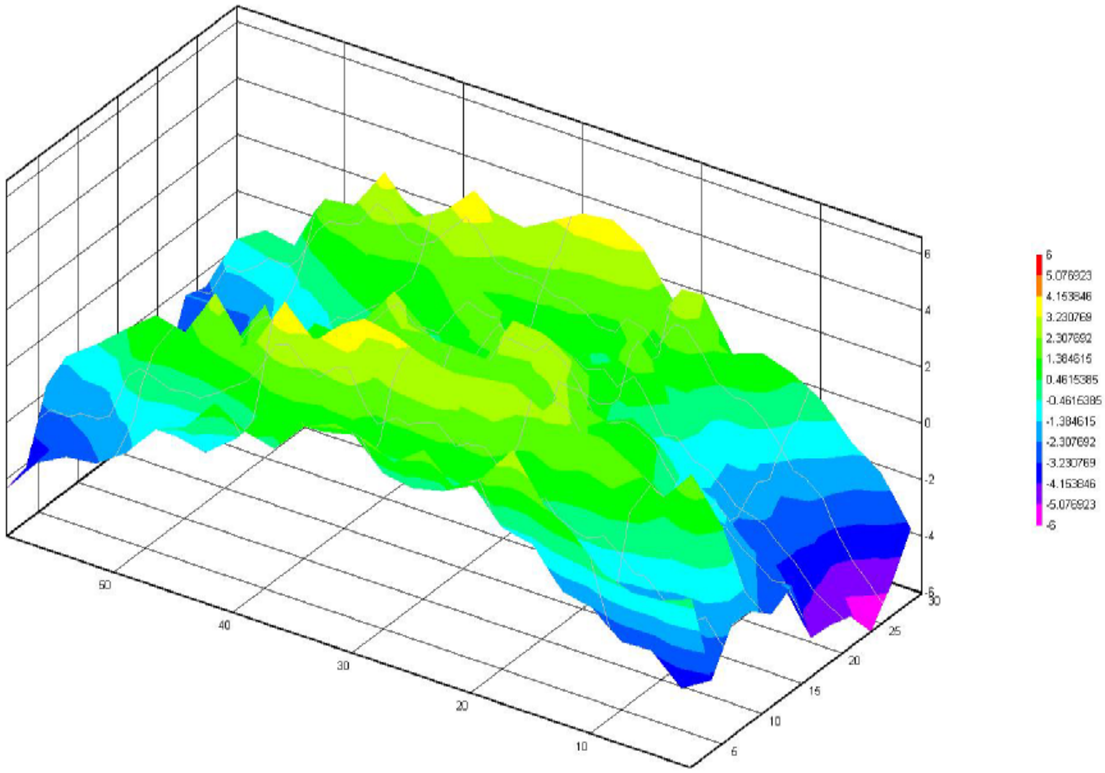


Figure 3. “Warp results” for CCD package S1-05. The plot is the shape at 173K minus the shape at 294K.

This warpage plot indicates a thermal deformation of about 7 or 8 microns. The base FEA case reported in Reference 4 predicted a 5.2 micron thermal deformation at this temperature. A contributing factor to the small difference might be the different CTEs and relatively uncontrolled clamping force between the Invar module foot and the aluminum storage box base plate.

MODULE THICKNESS MEASUREMENTS

Module thickness is measured to verify consistency between multiple modules to be packaged in an array. The nominal thickness is 13.788 mm. Two assembly steps contribute to maintaining uniform thickness; CCD gluing, which sets CCD flatness, and foot gluing, which is the dominant thickness driver. The CCD is glued to the AlN readout subassembly while the CCD surface is held flat against a porous ceramic plate to which vacuum is applied during epoxy curing. This plate, from Tru-Stone Technologies, is flat to 1.3 microns over 6" and sets the flatness of the CCD/AlN subassembly. This subassembly is then placed on the foot gluing fixture (shown below) that is used for final assembly.

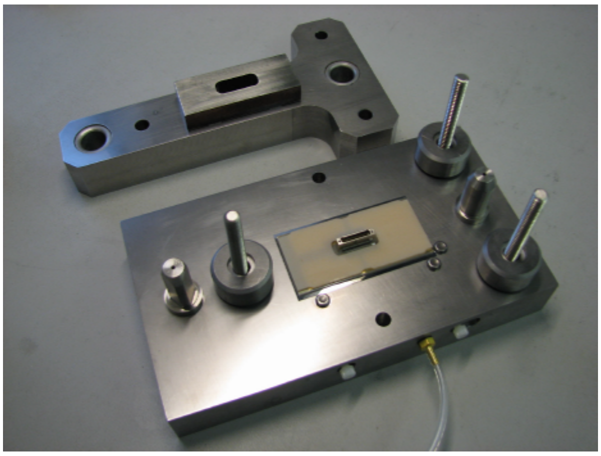


Figure 4. Foot Gluing Fixture

The CCD is held to the base plate with vacuum and the Invar foot is screwed to the bottom surface of the top plate. Three precision spacers are then used to set the overall height, and epoxy is applied by capillary action into the small gap resulting between the AlN and the Invar foot. CMM inspection results for the fixture plates are shown in Figures 4 and 5, below. The average spacer thicknesses were measured to be within 2 microns, and the flatness of the spacer faces is better than 5 microns. The same spacer was used in the same location (but not necessarily the same orientation) for every module, and a torque wrench was used to achieve a consistent clamping force on these spacers during each use of this setup.

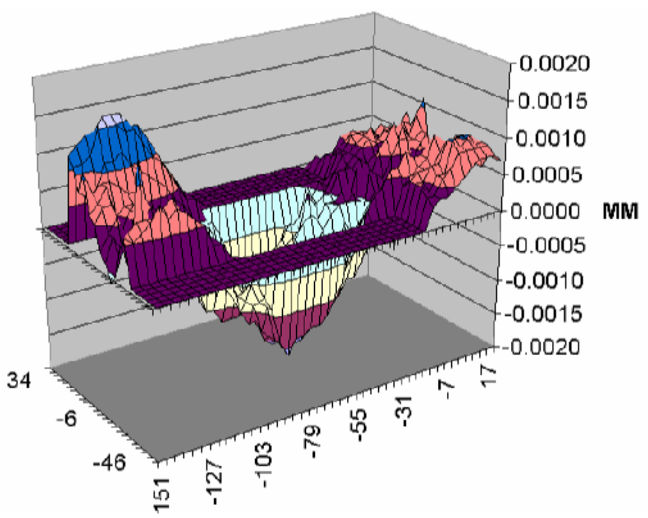


Figure 5. Foot Gluing Fixture Base Plate Flatness
(regions away from the CCD or the thickness spacers were not surveyed)

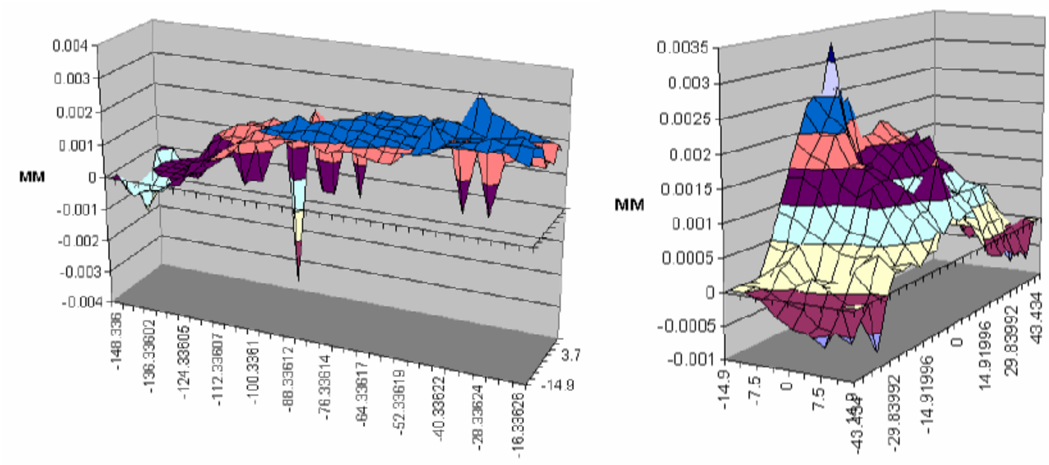


Figure 6. Top Plate Flatness (reported in two sections)

To perform the thickness measurement, the module, with its foot mounted on the foot gluing fixture top plate, was placed on the QC4000 CMM, which is configured with a Hamamatsu C2400-75 camera with a 20X lens. The CMM autofocus was first used to establish the XY plane on the top surface of the plate. Then an array of points was inspected on the CCD surface, with the Z values indicating total device thickness.

The accuracy of the QC4000 was checked by measuring the S1-01 module on this machine and on a B&S touch probe CMM (this was done after this module was already determined to be electrically non-functional). Plots of deviation from nominal with the two measurement systems are shown below, along with a comparison of the two.

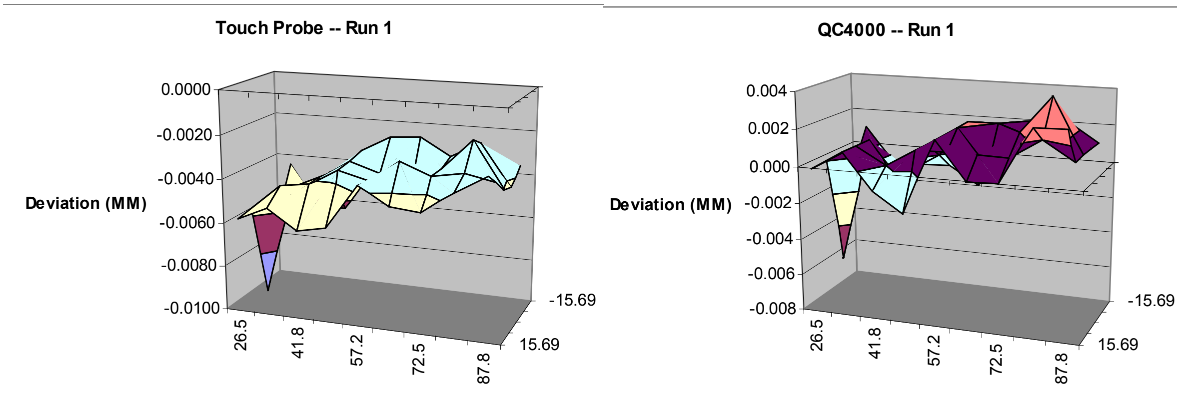


Figure 7. Thickness Measurements on S1-01 with both
B&S Touch Probe and QC4000 Optical CMMs

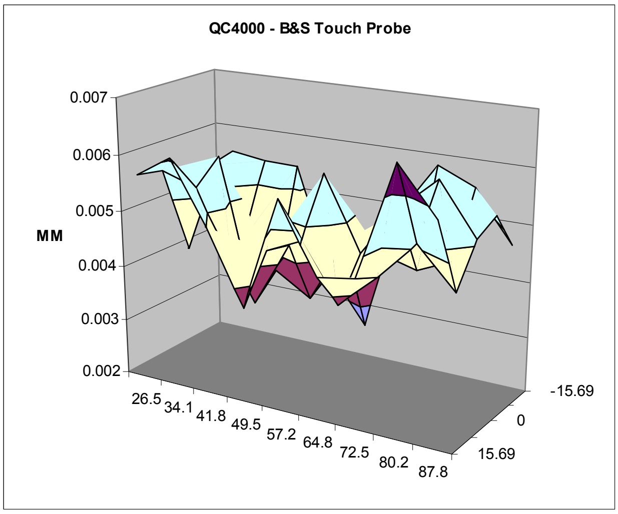


Figure 8. Measurement Difference Between the B&S Touch Probe and QC4000 Optical CMMs

The results indicate an average offset of 5 microns in the QC4000 data. Measurements performed with this system are therefore corrected by this amount when determining the deviations shown in the plots below for the eight modules that have been surveyed. These results are summarized in the following table:

Module #	Peak-to-Valley (microns)	Avg. Thickness (microns)	Comment
S1-01	9	-3.1	Dip in 1 edge
S1-02	6	-3.7	Tilt
S1-03	3	-7.2	---
S1-05	6	-3.7	Dip in 1 corner
S1-06	5	-4.7	---
S1-09	8	-3.3	Dip in 1 corner
S1-12	4	-5.1	---
S1-17	8	-4.3	Tilt

The average thickness numbers therefore indicate the following:

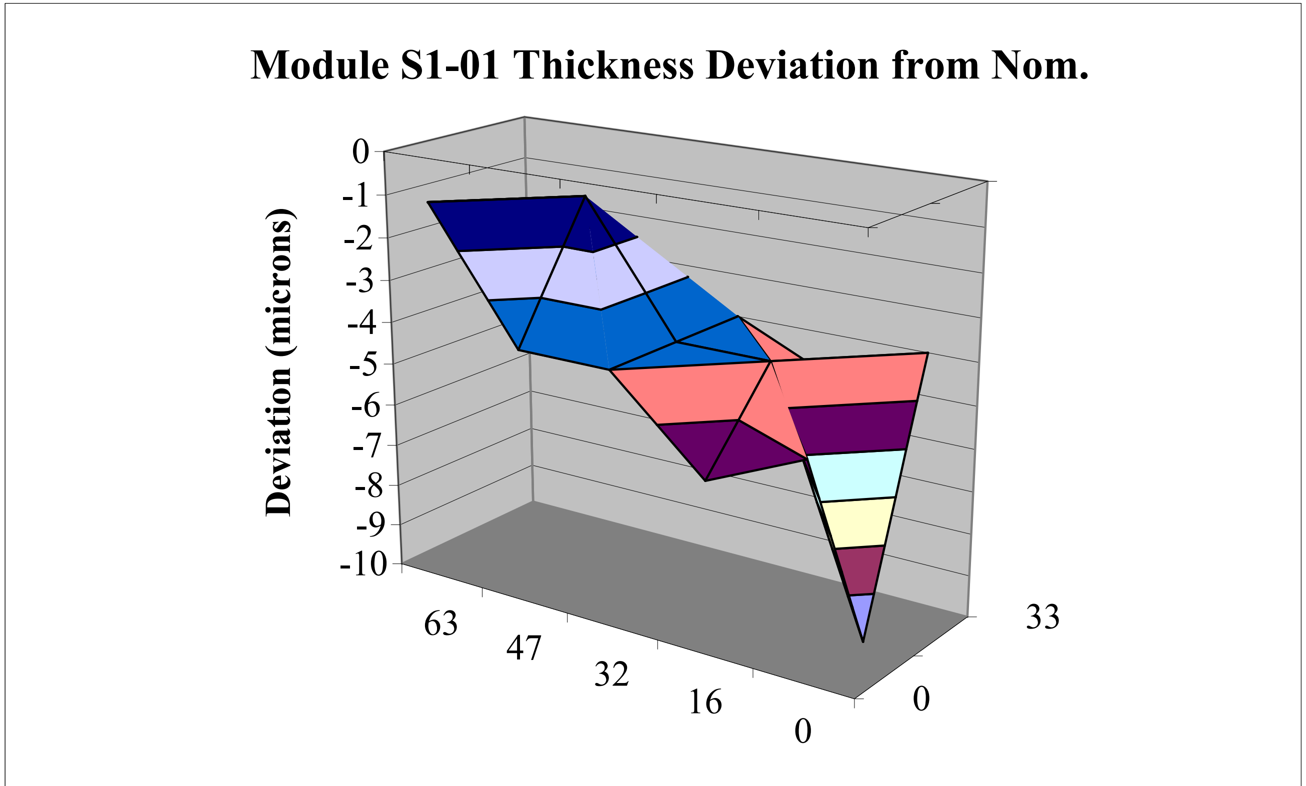
* Average of the average thicknesses: -4.4 microns
* Range of average thicknesses: 4.1 microns
* Std. Dev. of average thicknesses: 1.3 microns

Measurement date =	3/6/2007	by GED	-5

	0	17	33
63	13.7920	13.7890	13.7900
47	13.7890	13.7920	13.7880
32	13.7890	13.7890	13.7890
16	13.7870	13.7890	13.7880
0	13.7880	13.7830	13.7890

	0	17	33
63	-1	-4	-3
47	-4	-1	-5
32	-4	-4	-4
16	-6	-4	-5
0	-5	-10	-4

Average:	-4.3
Sigma:	2.1

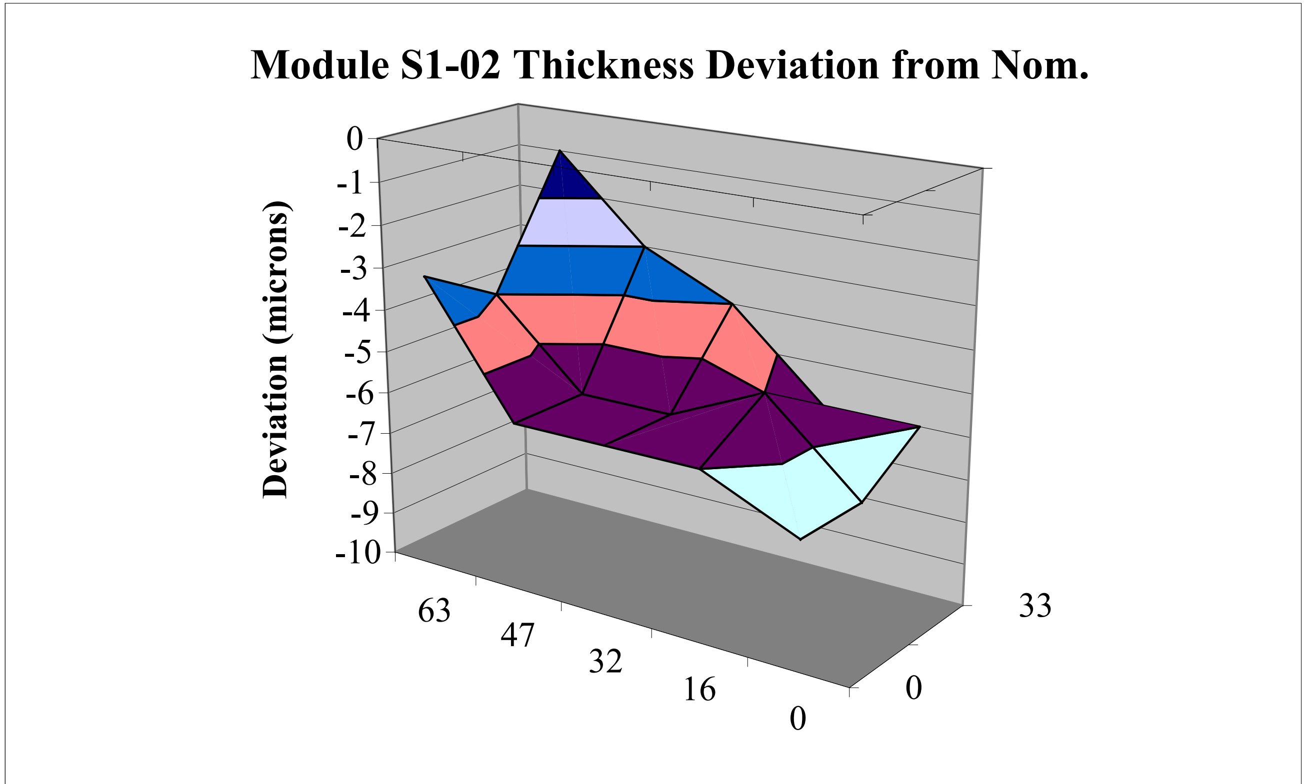


Measurement date =	3/6/2007	by GED	-5

	0	17	33
63	13.790	13.789	13.792
47	13.787	13.787	13.790
32	13.787	13.787	13.789
16	13.787	13.788	13.787
0	13.786	13.786	13.787

	0	17	33
63	-3	-4	-1
47	-6	-6	-3
32	-6	-6	-4
16	-6	-5	-6
0	-7	-7	-6

Average:	-5.1
Sigma:	1.7

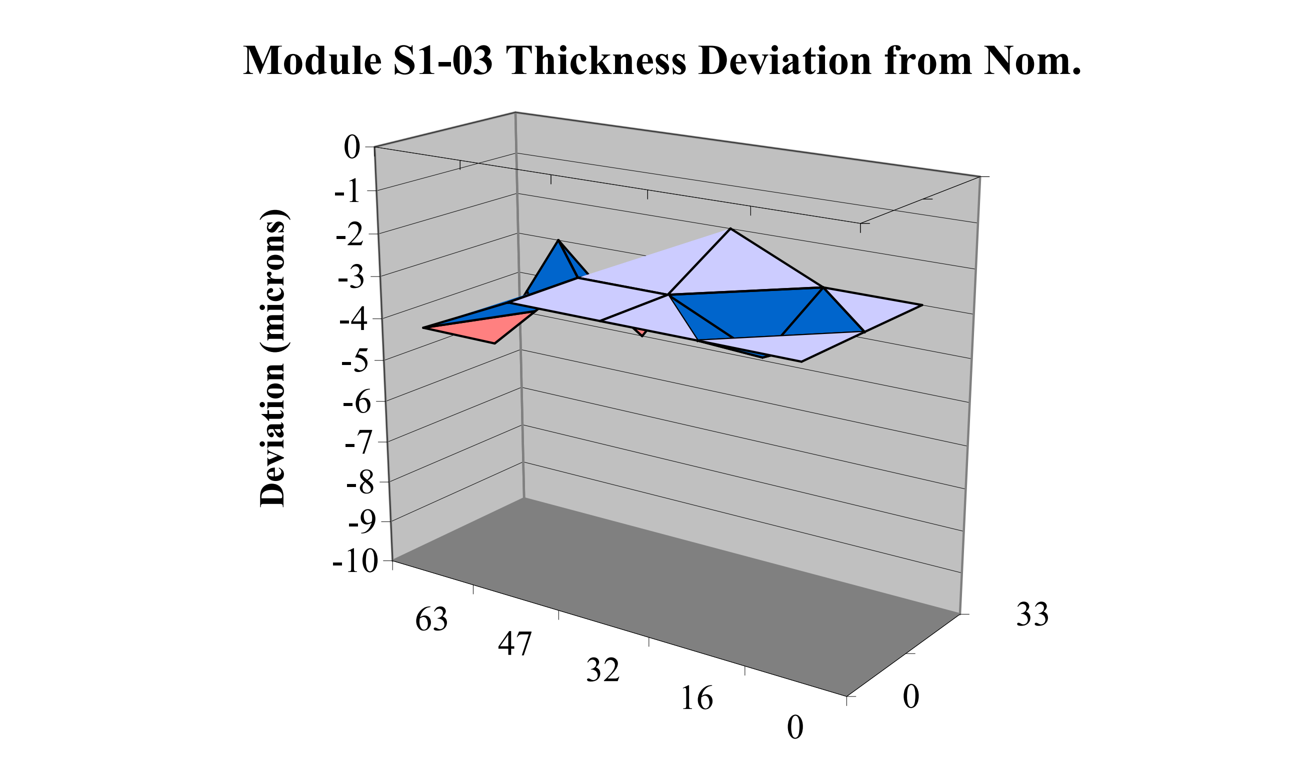


Measurement date =	3/7/2007	by GED	-5

	0	17	33
63	13.789	13.788	13.790
47	13.790	13.790	13.788
32	13.790	13.790	13.791
16	13.790	13.789	13.790
0	13.790	13.790	13.790

	0	17	33
63	-4	-5	-3
47	-3	-3	-5
32	-3	-3	-2
16	-3	-4	-3
0	-3	-3	-3

Average:	-3.3
Sigma:	0.8

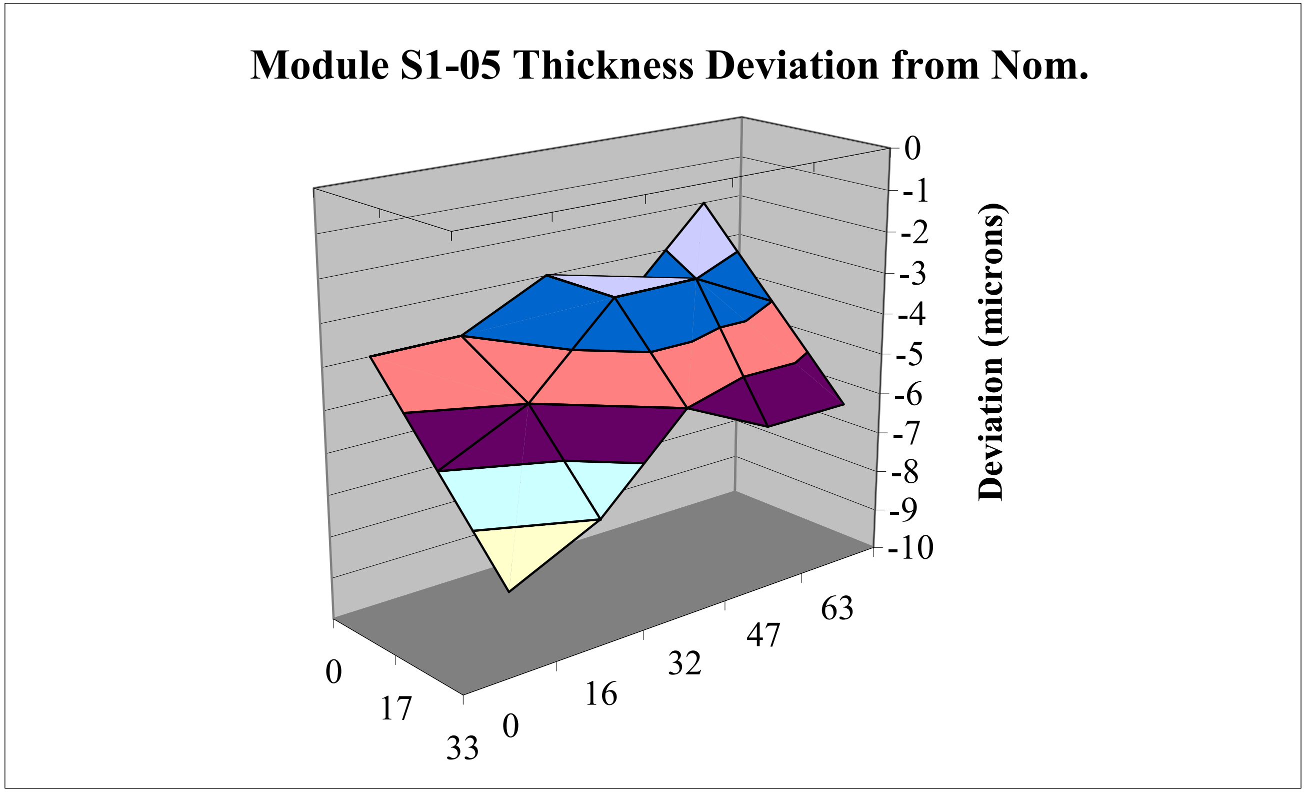


Measurement date =	3/7/2007	by GED	-5

	0	17	33
63	13.791	13.789	13.787
47	13.789	13.790	13.787
32	13.790	13.790	13.788
16	13.789	13.788	13.786
0	13.789	13.787	13.785

	0	17	33
63	-2	-4	-6
47	-4	-3	-6
32	-3	-3	-5
16	-4	-5	-7
0	-4	-6	-8

Average:	-4.7
Sigma:	1.7

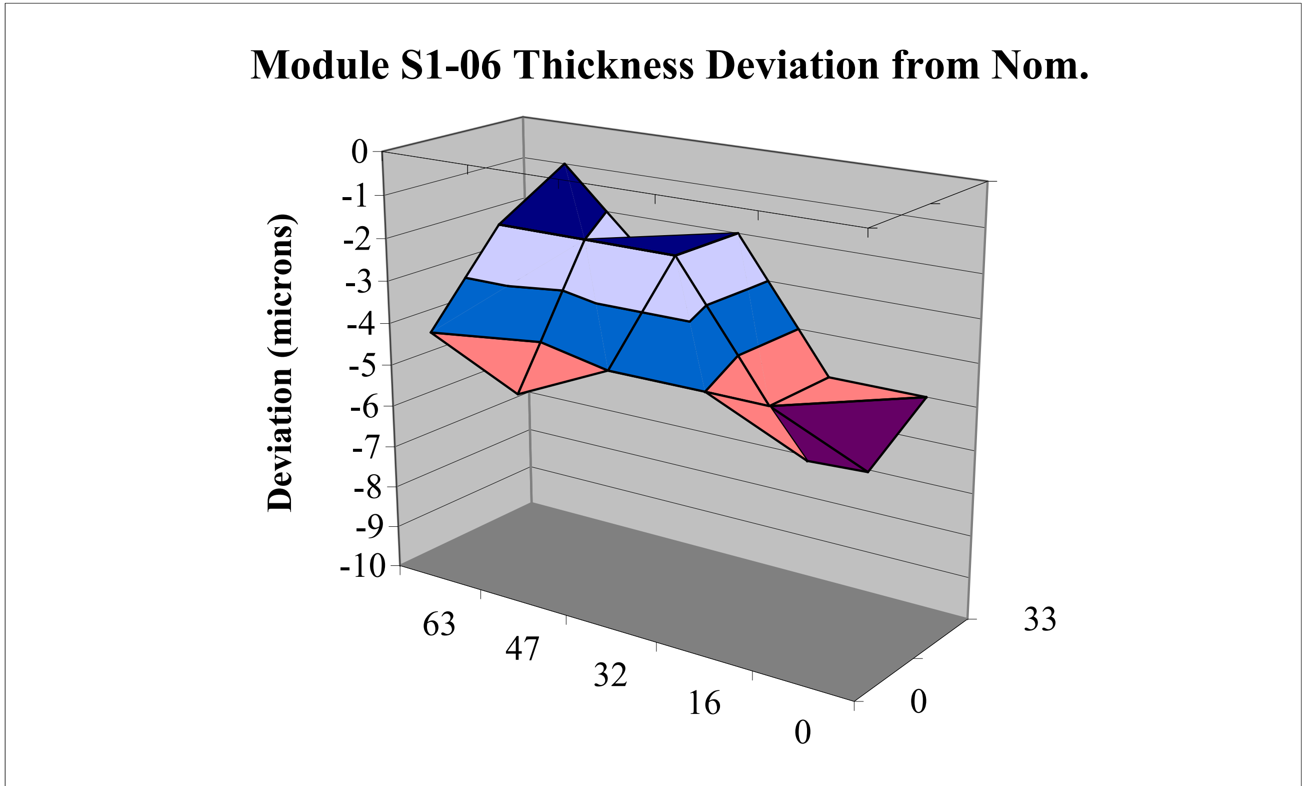


Measurement date =		5/8/2007	by GED				-5

	0	17	33
63	13.789	13.791	13.792
47	13.788	13.791	13.790
32	13.789	13.791	13.791
16	13.789	13.788	13.788
0	13.788	13.787	13.788

	0	17	33
63	-4	-2	-1
47	-5	-2	-3
32	-4	-2	-2
16	-4	-5	-5
0	-5	-6	-5

Average:	-3.7
Sigma:	1.5

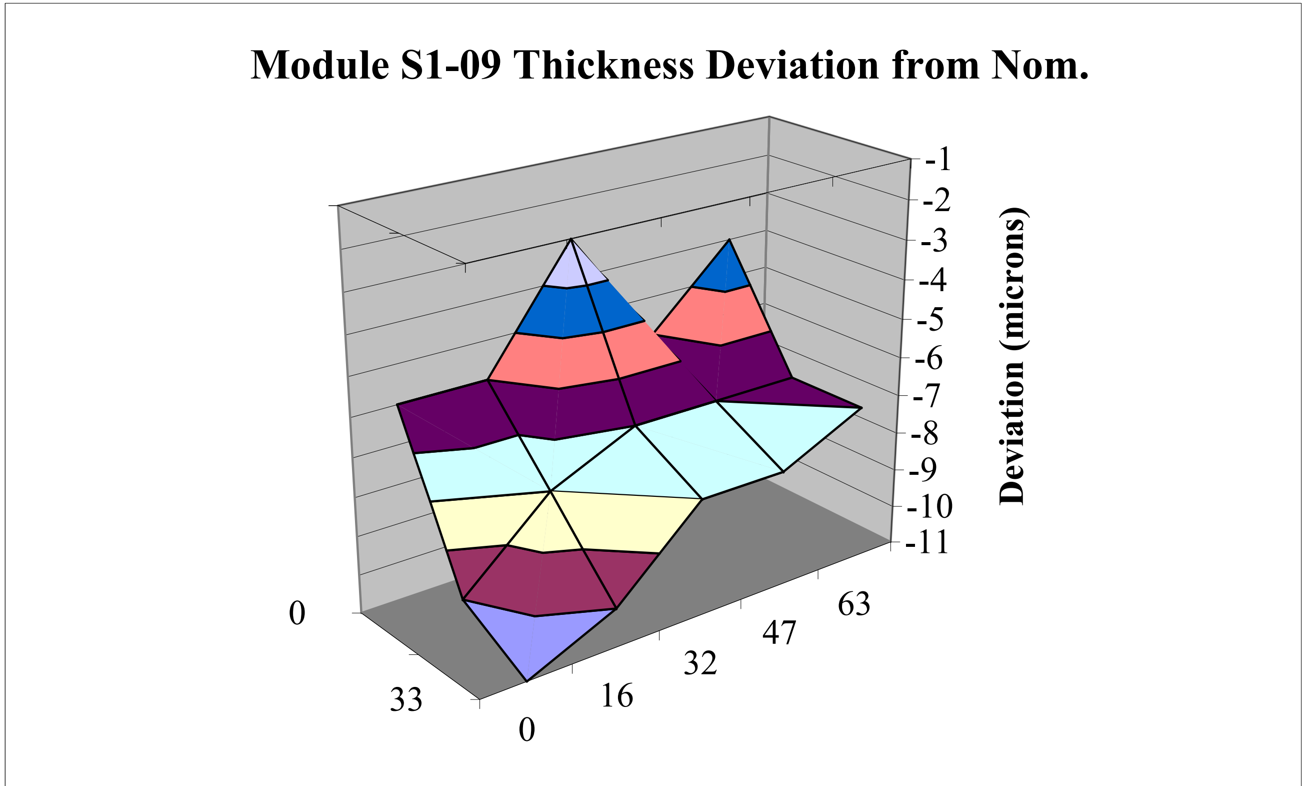


Measurement date =	5/29/2007	by GED	-5

	0	17	33
63	13.789	13.786	13.786
47	13.787	13.786	13.785
32	13.790	13.786	13.785
16	13.787	13.785	13.783
0	13.787	13.783	13.782

	0	17	33
63	-4	-7	-7
47	-6	-7	-8
32	-3	-7	-8
16	-6	-8	-10
0	-6	-10	-11

Average:	-7.2
Sigma:	2.1

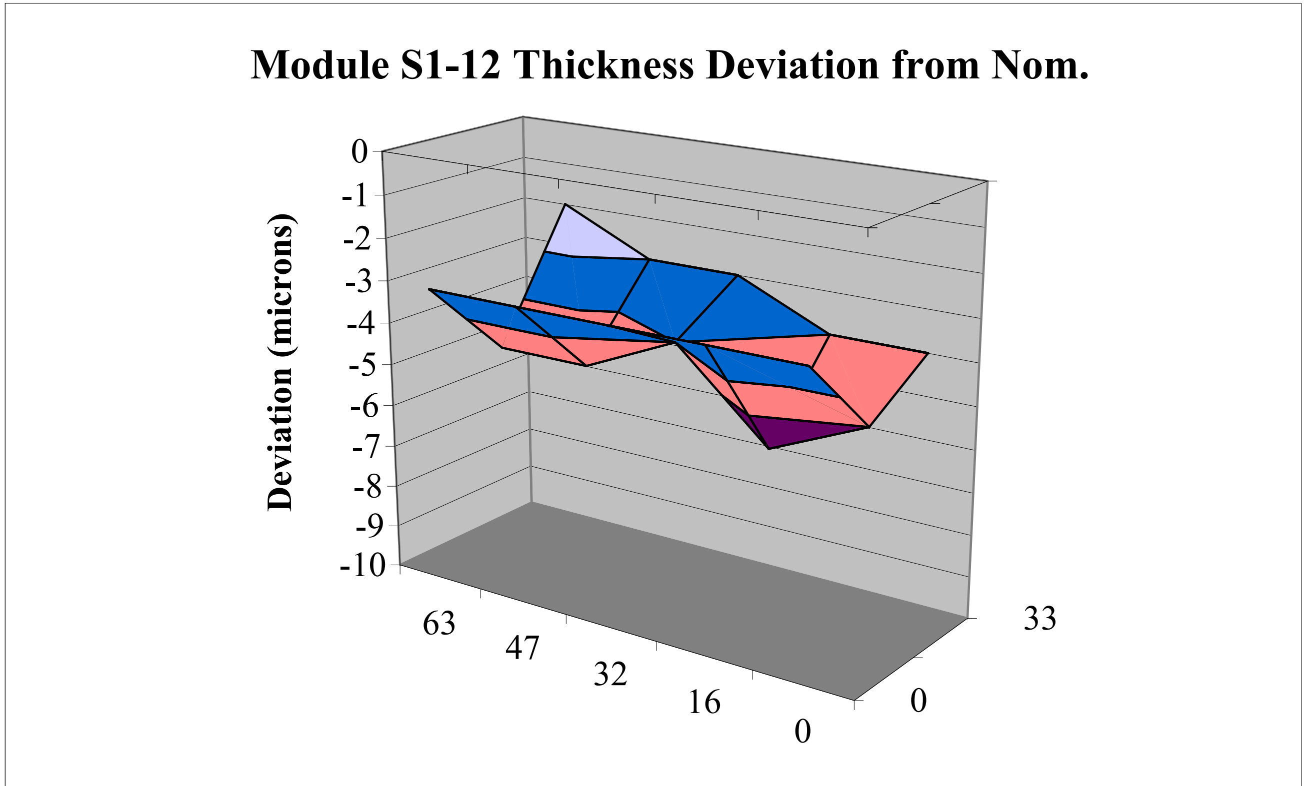


Measurement date =	3/8/2007	by GED	-5

	0	17	33
63	13.790	13.788	13.791
47	13.790	13.788	13.790
32	13.790	13.789	13.790
16	13.790	13.787	13.789
0	13.790	13.788	13.789

	0	17	33
63	-3	-5	-2
47	-3	-5	-3
32	-3	-4	-3
16	-3	-6	-4
0	-3	-5	-4

Average:	-3.7
Sigma:	1.1

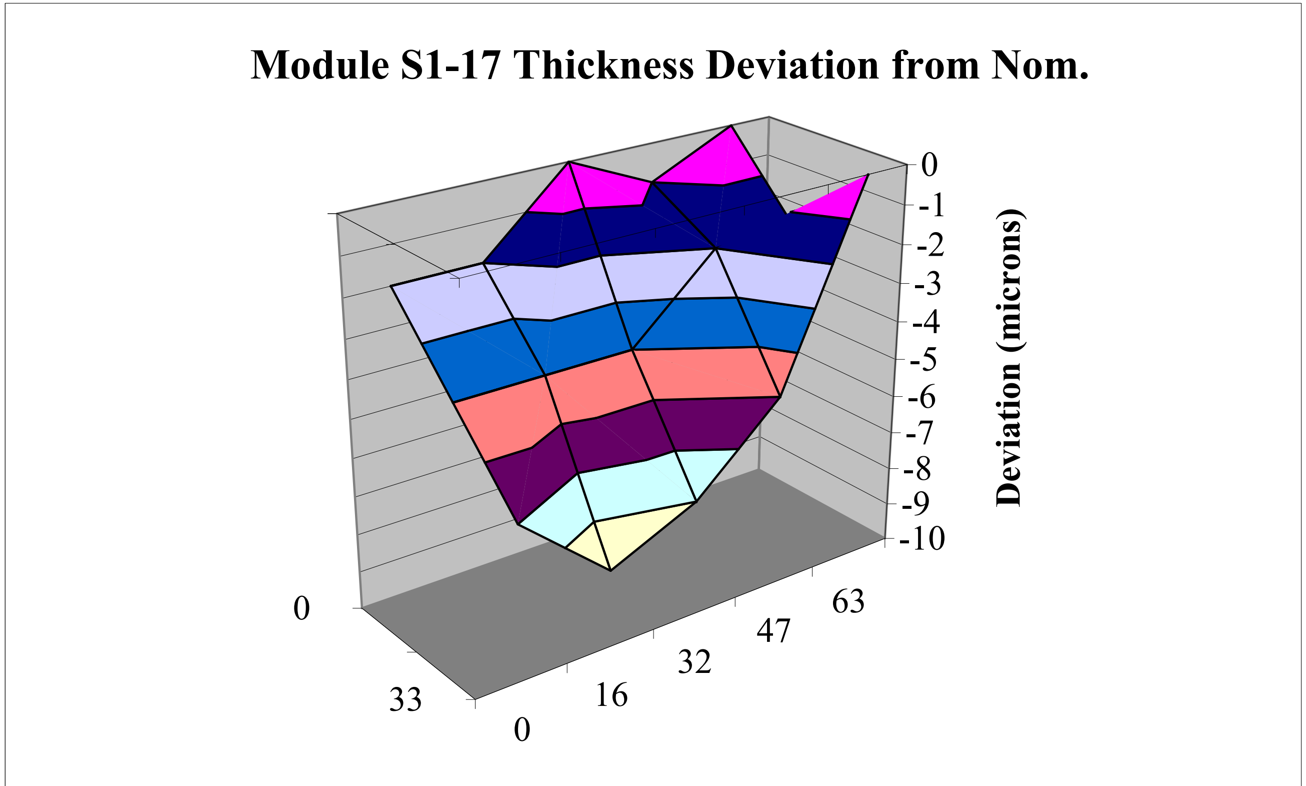


Measurement date =	by GED	-5

	0	17	33
63	13.793	13.791	13.793
47	13.792	13.791	13.788
32	13.793	13.789	13.786
16	13.791	13.789	13.785
0	13.791	13.789	13.787

	0	17	33
63	0	-2	0
47	-1	-2	-5
32	0	-4	-7
16	-2	-4	-8
0	-2	-4	-6

Average:	-3.1
Sigma:	2.6



CCD EDGE ALIGNMENT MEASUREMENTS

At the same time thickness measurements are performed, 10 points around the edge of the sensor are surveyed relative to features on the mounting plate in order to inspect the edge alignment accuracy. The CCDs do not have to be accurately aligned from a science requirement standpoint, but significant misalignments could potentially lead to problems when packing multiple CCDs into a tightly packed array.

It should be pointed out that at this level of magnification the edge of the Si is far from being a straight line; waviness and chipped edges are the norm. Selection of which points to measure is done by choosing points of maximum material projection in the immediate locality being surveyed. As discussed below, this was found to yield surprisingly repeatable results.

Once several modules were surveyed, it was noted that each had shifts (~80 microns) in exactly the same direction (+X in the CMM coordinate system). Re-inspection of the assembly tooling did not indicate any systematic problem there, so a module was rotated 90 on the CMM and resurveyed and was found to still have an offset in the +X CMM direction. This indicated that the Z axis was not square to the XY plane. The machine was then adjusted to better than 5 microns in XZ and YZ over a 14 mm height and all the module edges were re-inspected.

Several measurement runs were first performed on the same module to gauge the repeatability of the system:

	Case 1 (Initial Survey)	Case 2 (Rotate 90 degrees)	Case 3 (Remove & reinstall CCD)	Case 4 (Remeasure in same C.S.)	Case 2 - 1	Case 3 - 1	Case 4 - 3
1	88.824	88.819	88.838	88.837	-0.005	0.014	-0.001
2	88.814	88.814	88.836	88.836	0.000	0.022	0.000
3	16.657	16.663	16.649	16.650	0.006	-0.008	0.001
4	16.651	16.662	16.642	16.642	0.011	-0.009	0.000
5	16.644	16.647	16.631	16.632	0.003	-0.013	0.001
6	25.433	25.426	25.454	25.452	-0.007	0.021	-0.002
7	25.440	25.434	25.458	25.457	-0.006	0.018	-0.001
8	-16.668	-16.676	-16.694	-16.694	-0.008	-0.026	0.000
9	-16.674	-16.668	-16.683	-16.681	0.006	-0.009	0.002
10	-16.667	-16.657	-16.677	-16.676	0.010	-0.010	0.001

The differences between Case 1 and Case 2 found that the uncertainties associated with CMM squareness, reestablishing the coordinate system, and remeasuring the edges results in a maximum difference of 11 microns.

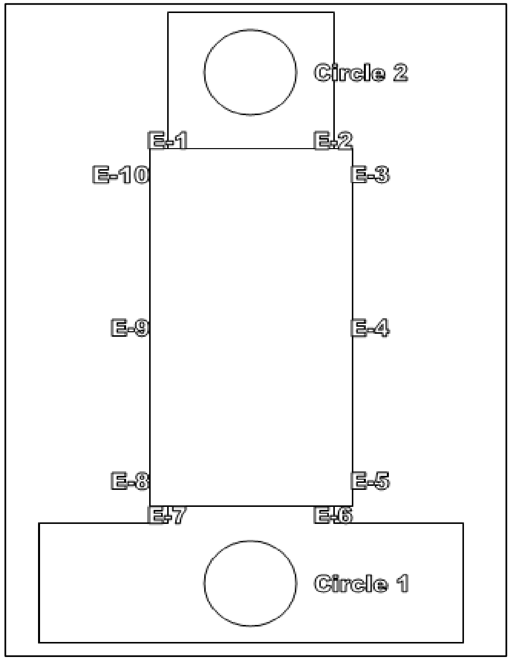
Removing the CCD from the plate and then reinstalling and remeasuring it found larger variations, as much as 26 microns, as shown by the difference between Case 3 and Case 1. This value is consistent with the amount the top plate holes are oversized relative to the module mounting pins pressed into the feet:

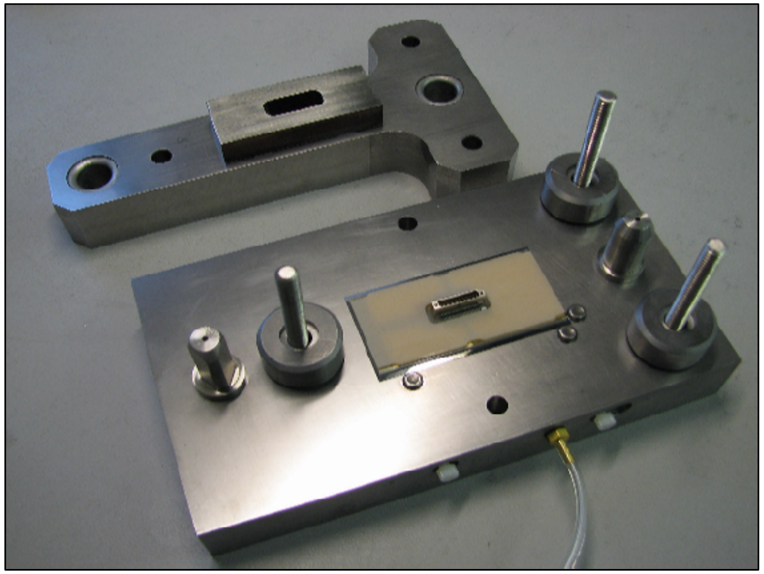
Round pin diameter difference = 4.781 (from CMM data) – 4.756 (min of lot measurement) = 0.025 mm
Diamond pin diameter difference = 3.196 (from CMM data) – 3.169 (min of lot measurement) = 0.027 mm

Case 4 remeasured the edges while still using the same coordinate system and was found to be extremely close to the Case 3 results even though different local spots were used for the measurements. This indicates that this measurement technique works quite well given the edge quality issues mentioned above.

A summary of the edge data for the seven modules that have been inspected are shown in the following table. The maximum deviation from nominal found was 38 microns. No systematic left/right shift was found, but an average top/bottom shift of 15 microns does appear in the data. This shift does not correlate to any alignment pin / hole measurement shifts in the CMM inspection of the fixture parts, but it is smaller than the random shifts expected from pin/hole engagements between the module & top plate and between the top plate & bottom plate. There does appear to be a small systematic rotation in the sensor position; the average rotation of 0.274 mrad equates to 1.1 pixels over the length of the CCD.

S1 Modules -- Silicon Edge Measurement Results





S1-___:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Average	Sigma
E1	-0.007	-0.004	-0.036			-0.018			-0.028			0.003					-0.024		-0.016	0.014
E2	-0.009	-0.004	-0.038			-0.016			-0.029			-0.022					-0.031		-0.021	0.012
E3	-0.009	0.003	0.010			0.021			0.012			0.017					0.008		0.009	0.010
E4	-0.016	-0.002	-0.002			0.009			-0.001			0.007					0.003		0.000	0.008
E5	-0.027	-0.007	0.006			0.001			-0.005			-0.015					-0.006		-0.008	0.011
E6	-0.001	-0.007	-0.020			-0.014			-0.012			-0.019					-0.028		-0.014	0.009
E7	0.003	-0.011	-0.024			-0.008			0.000			0.004					-0.021		-0.008	0.011
E8	-0.036	-0.027	0.005			0.000			-0.009			-0.017					-0.011		-0.014	0.014
E9	-0.025	-0.014	0.010			0.016			0.003			0.004					-0.003		-0.001	0.014
E10	-0.019	-0.017	0.019			0.025			0.009			0.020					0.006		0.006	0.018
Max Dev.:	0.036	0.027	0.038			0.025			0.029			0.022					0.031		0.030	0.006
L/R Shift Avg:	-0.022	-0.011	0.008			0.012			0.001			0.003					-0.001		-0.001	0.012
T/B Shift Avg:	-0.004	-0.007	-0.029			-0.014			-0.017			-0.009					-0.026		-0.015	0.010
Avg Theta (mrad):	0.265	0.152	0.136			0.341			0.265			0.523					0.235		0.274	0.130

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